Recovery Plan

for

Philippine Downy Mildew and Brown Stripe Downy Mildew of Corn

caused by
Peronosclerospora philippinensis and *Sclerophthora rayssiae* var. *zeae*, respectively

September 18, 200**6**

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This recovery plan is one of several disease-specific documents produced as part of the National Plant Disease Recovery System (NPDRS) called for in Homeland Security Presidential Directive Number 9 (HSPD-9). The purpose of the NPDRS is to insure that the tools, infrastructure, communication networks, and capacity required to mitigate the impact of high consequence plant disease outbreaks are such that a reasonable level of crop production is maintained.

The disease-specific plans are intended to provide a brief primer on the disease, assess the status of critical recovery components and identify disease management research, extension and education needs. These documents are not intended to be stand-alone documents that address all of the many and varied aspects of plant disease outbreak, response, and recovery. They are documents that USDA will use to guide further efforts directed toward plant disease recovery.

Executive Summary

Philippine downy mildew of maize (PDM), caused by the oomycete *Peronosclerospora philippinensis* and Brown stripe downy mildew (BSDM) caused by *Sclerophthora rayssiae* var. *zeae* are destructive diseases of corn in tropical Asia. These are two of several downy mildew diseases that occur in China, India, Indonesia, Nepal, Pakistan, and Thailand. Neither disease has been reported within the U.S.

Corn is the common host for both species. PDM also infects cultivated sugarcane, some sorghum cultivars, and many weedy grass species, including wild species of sorghum and sugarcane, and common perennial grasses of the U.S., such as big bluestem *(Andropogon gerardii*) and little bluestem (*Schizachyrium scoparium*). BSDM has been reported to infect several species of crabgrass (*Digitaria)***.**The source of primary PDM infection in corn comes from spores produced by nearby infected hosts such as sugarcane or susceptible grass species. The PDM is most commonly spread by wind and rain. Production of spores requires night temperatures ranging from 70 to 79ºF accompanied by free moisture. Wind dispersal of the downy mildew pathogens results in localized spread among fields in a given geographical region. Though the pathogen has been detected systemically in seed, it has been clearly demonstrated that once the seed or grain is dried down below 14% it will not produce an infected plant

In the case of BSDM, the source of primary infection is from soil borne over-wintering spores which germinate in saturated wet soil producing both conidia and swimming zoospores which infect the young plants. Optimum temperature range for infection is 68 to 77ºF. Wind and rain dispersed conidia produced on the surface of infected leaves are the source of secondary disease spread.

Annual yield losses in the Philippines from PDM on corn have been 40 to 60% on farms across the country. On sweet corn, losses of 100% have been reported. It was estimated that the national yield loss in the 1974-1975 growing season was 8%, which was valued at U.S. $23 million. Much less data are available on yield losses on sugarcane, but losses in the harvested and extracted sugar of 35% have been noted. Disease severity is highest in areas that receive 39-78 inches of rain annually and in tropical climates.

In India, yield losses from BSDM reportedly range from 20-60%, occasionally reaching 70% in certain areas. Disease incidence increases in tandem with annual rainfall, the most favorable being 40 to 80 inches. Economic losses in 1976 were estimated at $1.1 million.

Focused, national efforts are needed to determine the potential impact of these diseases if they were to infect the U.S. corn crop. In addition, a survey of available resistant germplasm is needed along with a categorization of efficacious fungicides that could be approved by EPA in case of a national need.

Philippine Downy Mildew and Brown Stripe Downy Mildew of Corn
caused by
Peronosclerospora philippinensis and *Sclerophthora rayssiae* var. *zeae*, respectively

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Reviewers: The American Phytopathological Society

I. Introduction

Twenty-one species of downy mildew have been reported to be pathogenic to grass species (4). Of these, eight are reported as pathogens of corn. Three downy mildew diseases have been reported on corn in the United States: green ear downy mildew, crazy top, and sorghum downy mildew.

Philippine downy mildew of maize (PDM), caused by the oomycete *Peronosclerospora philippinensis* and Brown stripe downy mildew (BSDM) caused by *Sclerophthora rayssiae* var. *zeae* are destructive diseases of corn in tropical Asia. These are two of several downy mildew diseases that occur in China, India, Indonesia, Nepal, Pakistan, and Thailand (6). Neither disease has been reported within the U.S.

Corn is the common host for both species. PDM also infects cultivated sugarcane, some sorghum cultivars, and many weedy grass species, including wild species of sorghum and sugarcane, and common perennial grasses of the U.S., such as big bluestem *(Andropogon gerardii*) and little bluestem (*Schizachyrium scoparium*). BSDM has been reported to infect several species of crabgrass (*Digitaria)* (3)**.**

II. Symptoms

Early field symptoms alone cannot be used for diagnosis of PDM or BSDM. Many plant pathogens, including some indigenous downy mildews and physiological conditions (fertility, weather, etc.) can cause similar symptoms. A non-indigenous closely related species, *Peronosclerospora sacchari*, also attacks corn, sorghum and sugarcane producing almost identical symptoms to that of PDM. Hence, caution is needed in concluding that plant symptoms shown below are caused by the exotic downy mildews of concern.

The first symptoms of downy mildew on corn typically appear as chlorotic stripes at the first leaves as early as 9 days after planting (7), (Figure 1). All leaves on a plant may show characteristic symptoms of long chlorotic (yellow) streaks (Figure 2). The surest indication of the disease is a downy covering on the underside of the leaves. This covering is the site of spore production and the source for secondary spread of the disease to other susceptible corn plants. (Figure 3). As the plant ages, leaves may narrow, become abnormally erect, and appear somewhat dried out (Figure 5). As the corn plant matures, tassels become malformed, ear formation is interrupted, and sterility of seeds results.

The National Plant Diagnostic Network has developed standard operating procedures for handling and diagnosis of brown stripe downy mildew.

Figure 1. Early symptoms of a) Philippine downy mildew on corn appear as chlorotic stripes on leaves. Photo courtesy of C. De Leon. Reprinted from Shurtleff, M.C. 1983, Compendium of Corn Diseases, Second Edition, American Phytopathological Society, St. Paul, MN.

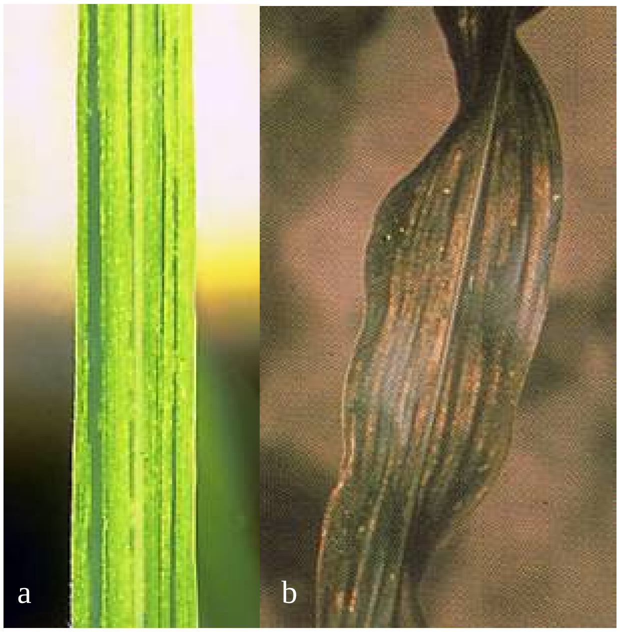

Figure 2. a) Typical chlorotic streaks of Philippine downy mildew on corn. Courtesy of B.L. Renfro. b) Well defined lesions of brown stripe downy mildew on corn are initially limited by the leaf veins. Photo courtesy of A.J. Ullstrup and B.L. Renfro. Reprinted from Shurtleff, M.C. 1983, Compendium of Corn Diseases, Second Edition, American Phytopathological Society, St. Paul, MN.

Figure 3. The greenish gray color of this leaf is a typical downy mildew symptom. Photo courtesy of C. De Leon. Reprinted from White, D.G. 1999, Compendium of Corn Diseases, Third Edition, American Phytopathological Society, St. Paul, MN.

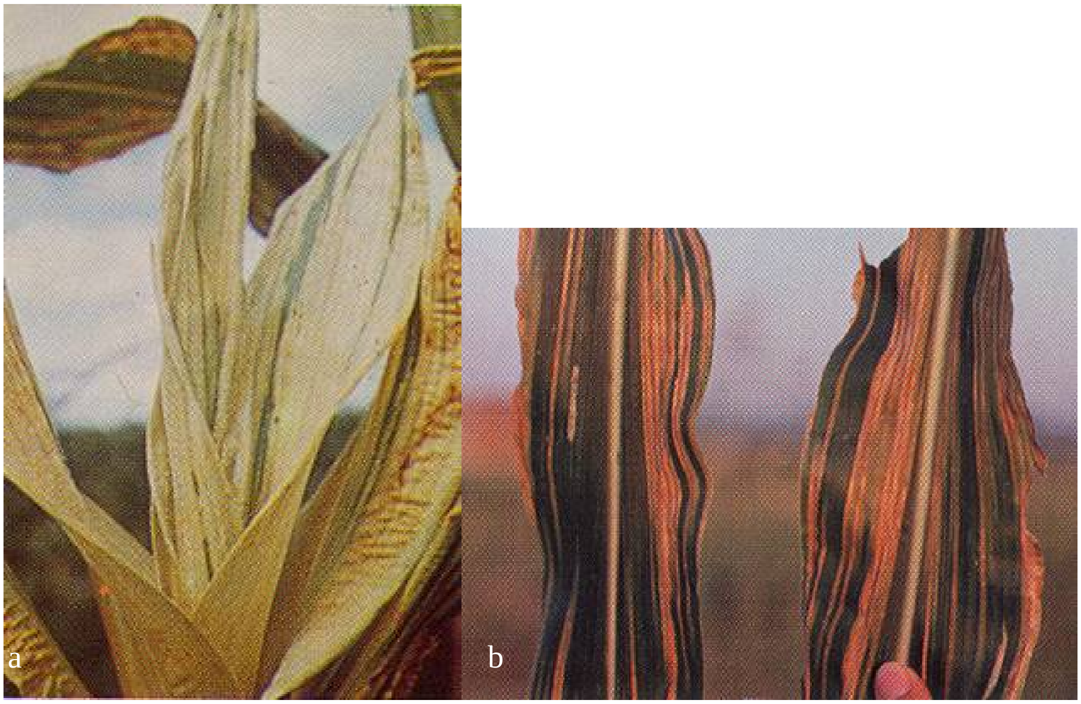

Figure 4. a) Older leaves of plants infected with Philippine downy mildew are often abnormally erect and appear somewhat dried out. Photo courtesy A.J. Ulstrup and B.L. Renfrow. Reprinted from 1973, A Compendium of Corn Diseases, American Phytopathological Society, St. Paul, MN. b) Advanced symptoms of brown stripe downy mildew on corn. Photo courtesy C. De Leon. Reprinted from White, D.G. 1999, Compendium of Corn Diseases, Third Edition, American Phytopathological Society, St. Paul, MN.

III. Biology and Spread

The source of primary PDM infection in corn comes from the fragile spores (conidia) produced by nearby infected hosts such as sugarcane or susceptible grass species. Although PDM is reported to produce an over-wintering spore form (oospore), its role in the lifecycle has not been established. The PDM is most commonly spread by wind and rain. Production of conidia requires night temperatures ranging from 70 to 79ºF accompanied by free moisture. Wind dispersal of the downy mildew pathogens results in localized spread among fields in a given geographical region. Though the pathogen has been detected systemically in seed, it has been clearly demonstrated that once the seed or grain is dried down below 14% it will not produce an infected plant (1).

In the case of BSDM, the source of primary infection is from soil borne oospores (over wintering stage) which germinate in saturated wet soil producing both conidia and swimming zoospores which infect the young plants. Optimum temperature range for infection is 68 to 77ºF. Wind and rain dispersed conidia produced on the surface of infected leaves are the source of secondary disease spread.

IV. Diagnosis

Differentiating PDM from the endemic maize and sorghum pathogen (*P. sorghi*) can be accomplished microscopically based on clear differences in the conidiophore morphology. Likewise, BSDM can be differentiated from all of the other corn infecting *Peronosclerospora* spp. based on spore morphology. Due to the overlap in morphology, intraspecific variability in symptoms, and pathogenicity, separation of PDM and *P. sacchari* may prove to be the most difficult. No molecular diagnostic assays exist at this time to identify and differentiate the downy mildew Peronosclerospora spp (5). The ultimate authority for confirming a diagnosis of the disease rests with the Plant Protection and Quarantine (PPQ) division of APHIS: http://www.aphis.usda.gov/ppq

V. Survey and Detection

This recovery plan should include the development of a coordinated framework for survey, detection and prediction of corn downy mildews. This proposed framework is based on a framework constructed for soybean rust (APHIS, 2005). The framework for corn downy mildews would be delivered with consensus-building and commitment of cooperating parties such as USDA, Land Grant Universities, Industry and State Government. Three basic deliverables of the framework include a i) Surveillance and monitoring program; ii) Web-based system for information management; and iii) Prediction modeling. The development of decision criteria for management and training for cooperators would also be important components of the framework document but will not be discussed in detail.

1) Deliver a surveillance and monitoring network to provide timely information of the incidence and severity of corn downy mildew in the United States and off-shore source areas such as the Caribbean Basin.

A surveillance system may be composed of a number of separate components including sentinel plots, mobile teams, passive surveillance, industry data and spore sampling. Sentinel plots are susceptible plantings kept unsprayed and surveyed periodically by scouts. Mobile teams are groups who target specific locations or areas based on weather or pest models. Scouting data is also contributed by industry. Diagnostic clinics including Federal (APHIS and ARS), State (including the National Plant Diagnostic Network (NPDN) provide diagnostic data. Diagnostic samples may originate from walk-ins, from sentinel plots, mobile teams or from first responders. Industry also provides another source of surveillance data. The surveillance system is organized by the lead USDA agency, who liaises with state and federal agencies to coordinate a leadership structure on a state by state basis. Off-shore observations may also be important for establishing source areas for predictive modeling efforts.

2) Provide a web-based system (USDA Corn Downy Mildew Monitoring and Prediction System) for information management of monitoring observations, forecasts, and decision criteria to stakeholders.

Field and diagnostic observations need to flow into a web-based information system, which is termed the Corn Downy Mildew Monitoring and Prediction System (CDM-

MPS). In the following description, the potential for a CDM-MPS web site is based on sites constructed for other exotic pests such as soybean rust and citrus greening. The site is a powerful on-line database with tools for viewing geographic data sets. The CDM-MPS consists of a password protected web site for exchange of site-specific and sensitive information and a public web-site to communicate with stakeholders. The maps on public site show only which counties are positive as posted by the State Plant Health Director. The public site includes a national commentary and links to other sites. The password restricted web site contains detailed geocoded data and consists of separate user accounts for observers, state specialist, researchers and associates. The observer site consists of a series of on-line tools for uploading data. These tools include on-line forms, uploadabale spreadsheets and PDA software. The specialist site contains a set of tools for updating the public map and documents for stakeholders that appear on the system when a user zooms into the state. The researcher site allows experts to provide national guidance to state specialists. This might include interpretation of prediction model output or commentary. Associate access allows users such as administrators to view data and maps but not to make changes or to upload data.

3) Prediction modeling

An important part of the framework is the delivery of predictive models for corn downy mildew. These maps are delivered within the password protected web-site. Models could vary from simple to complex. At the simple end of the scale the model may represent the climatological likelihood that the pathogen could establish in the United States. More complex models could also be deployed through the site and might include sophisticated aerobiological tools. For soybean rust, APHIS cooperators at PSU, NCSU and ISU have developed aerobiological models that utilize hourly weather data to predict source production, transport, deposition and infection. The models include host phenology and distribution allowing the model to provide real time and forecast output at a $10km^2$ resolution. The creation of a suitable prediction model for corn downy mildew may require the collaboration of scientist from ARS, APHIS and land grant universities. Importantly, experience has shown the successful model operation requires feedback from field observations.

VI. Economic Impact and Compensation

Annual yield losses in the Philippines from PDM on corn have been 40 - 60% on farms across the country. On sweet corn, losses of 100% have been reported. It was estimated that the national yield loss in the 1974-1975 growing season was 8%, which was valued at U.S. $23 million. Much less data are available on yield losses on sugarcane, but losses in the harvested and extracted sugar of 35% have been noted. Disease severity is highest in areas that receive 39-78 inches of rain annually and in tropical climates.

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The USDA Risk Management Agency (RMA) coordinates compensation for growers who sustain crop damage from several different types of perils. The following table from the USDA/RMA web site lists the most common crop insurance programs that may be considered for insuring against losses from corn disease infestations as well as other types of risk.

Policy Name	Policy #	Ref #
MULTIPLE PERIL INSURANCE PROGRAM		
Coarse Grains ** See mandatory endorsement - footnote #10*	98-041	4, 10
GROUP RISK PLAN		
Corn	00-141	6
CROP REVENUE COVERAGE (CRC) PROGRAM		
Coarse Grains ** See mandatory endorsement - footnote #10*	02-CRC-CG	8, 10
REVENUE ASSURANCE (RA) PROGRAM		
Corn and Soybean	04-RA-Corn & Soybeans (Ed. Rev. 07/25/03)	12
GROUP RISK INCOME PROTECTION PROGRAM (GRIP)		
Corn	05-GRIP-CORN	9
GRIP - Harvest Revenue Option Endorsement	04-GRIP-HRO	9

VII. Mitigation and disease management

Any disease mitigation strategy that is utilized should be coordinated with Federal, State and local regulatory officials.

Chemical control: Several products are available, including Duter and Dithane M-45, Dexon, Cela, azoxystrobin, chlorothalonil, metalaxyl, and mefanoxam. Mefanoxam and metalaxyl are curative and protectant systemics. Control of these downy mildews could potentially be accomplished with a seed treatment with mefanoxam or metalaxyl (2). It is not known if these products are labeled for use on corn for downy mildew control, as most corn downy mildews are not currently in the U.S.

Biological control—At this time there are no known biological controls available for the prevention or treatment of the corn downy mildews.

Cultural control—Early research has shown the U.S. corn cultivars have little resistance to PDM. Resistant cultivars are available from foreign sources. Drying seed to < 14% moisture will prevent seed transmission of the disease.

There is little information regarding the resistance of U.S. cultivars to BSDM, however resistant germplasm is available from foreign sources. Since infection requires water saturated soil, planting outside the rainy season will reduce disease incidence.

VIII. Research, Education and Extension Priorities

Research priorities – short term

1. Obtain geographically distinct isolates of *P. philippinensis* and *Sclerophthora rayssiae* var *zeae* and near neighbor species with density and distribution represented in collections as needed for population studies and molecular finger printing.

    a) To accomplish this, establish cooperative agreements with scientists in originating countries (India, Philippines, China, and Taiwan, Indonesia et al) to obtain and establish viable isolates at ARS FDWSR, Fort Detrick, MD.

2. Use molecular sequence information from isolate and species collections to develop species-specific molecular detection tools, focusing on real-time PCR diagnostic assays for deployment at NPDN clinics.

3. Based on known downy mildew biology, develop beta versions of predictive models for spread and establishment.

Education Priorities – short term

4. Compile and develop digital images of disease symptoms and pathogen morphology on relevant hosts and distribute via the NPDN.

5. Develop a short course for first detectors indicating what to look for and how to recognize downy mildews.

6. Compile bibliography of downy mildew related scientific and technical literature, including collections from originating countries. Develop database of citations and distribute via the NPDN and researchers.

Extension Priorities – short term

7. Gather current information on industry activities related to the testing of more recently developed fungicides (e.g. strobilurins, azoles, etc,) for maize downy mildew control in Asia.

8. Determine fungicide product label registration status for maize, sorghum and sugarcane based on chemistries in use in Asia.

9. Deploy first detector training course.

10. Prepare picture cue field guides and educational materials for the extension and crop advisor community, advising them to be on the lookout for mildews in corn and how and where to take suspicious samples.

Research priorities - long term

1. Confirm or refute published assertions that *Peronosclerospora. philippinensis* does not produce the oospore over-wintering stage in sugarcane or maize.

    a. Determine if *P. philippinensis* produces oospores in the known wild grass alternative hosts common in the US maize growing regions.
    b. Determine the potential role of oospores produced by *P. sacchari*, the closely related sugarcane and maize pathogen, in the lifecycle of the disease.

2. Arrange for Asian testing of U.S. maize lines for *P. philippinensis* and *S. rayssiae* var *zeae* resistance (Philippines, Papua New Guinea, India?).

3. Investigate recent reports of *P. philippinensis* metalaxyl resistance in the Philippines and implications for US maize production.

    a. If warranted, conduct fungicide efficacy experiments for *P. philippinensis* and *S. rayssiae* var *zeae* in the Philippines and India.

4. Develop geophytopathological models to predict the establishment and spread potential of *P. philippinensis* and *S. rayssiae* var *zeae* in the U.S.

    a. Identify available sources of maize resistance suitable for growing in highest risk areas of U.S.
    b. Develop an action plan (Section 18 emergency registrations) for fungicides in states within highest risk areas of U.S.

5. Characterize the survival potential of *Sclerophthora rayssiae* var *zeae* oospores in soil

6. Determine the effects of soil temperature and moisture on germination of oospores of *S. rayssiae* var *zeae* and disease potential.

7. Determine the relationship between maize susceptibility to sporidial and zoospore infection and plant growth stage.

8. Determine the internal and external maize seed transmission potential of *S. rayssiae* var *zeae.*

9. Determine effects of temperature and dew period on spore viability, germination, and infection of maize by sporidia and zoospores of *S. rayssiae* var *zeae.*

Education Priorities – long term

1. Educate a new cadre of plant pathologists in the epidemiology of phycomycetes, and the population dynamics that cause loss of pathogen sensitivity to fungicides.

2. Develop training courses on management of downy mildew diseases and management of fungicide resistance

Extension Priorities – long term

1. Educate county extension, growers and crop advisors in the utility of map-based tracking and information systems such as the Pest Information Platform for Education and Extension (PIPE).

Additional Recommendations

Characterize the risk potential of other non-endemic, closely related maize downy mildews to U.S. Agriculture. The workshop group targeted a potentially new and little studied, emerging species of maize downy mildew in southern Nigeria.

IX. Infrastructure and Experts Listing

Infrastructure to handle research on the pathogens of the maize downy mildews is limited due to their select agent status. To conduct experiments with the pathogens, registration is required with USDA/APHIS. Registration is approved on a site-specific basis, taking into account geographical location, research objectives (i.e. if plant inoculation will be conducted), security measures, and a variety of other factors. In addition, the possession, use, or transfer of maize downy muldew or its pathogens requires entity registration. Permits are only required if movement of cultures or infected plant materials will occur across state or international lines.

Research projects concerning maize downy mildew are active at the USDA-ARS facilities in Ft. Detrick Maryland.

The following experts on the maize downy mildews have been identified:

H. L. Warren (retired)	Virginia Polytechnic Inst.	hwarren@vt.edu
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7. White, D.G. 1999, Compendium of Corn Diseases, Third Edition, American Phytopathological Society, St. Paul, MN. 128 pp.

Web Resources

http://arjournals.annualreviews.org/doi/abs/10.1146/annurev.py.15.090177.001341#search=%22maize%20downy%20mildew%22

http://www.ars.usda.gov/research/projects/projects.htm?ACCN_NO=410075